MANOCK

Cost and Methods of

Constructing a concrete sewer

Civil Engineering

B. S.

1910

COST AND METHODS OF CONSTRUCTING A CONCRETE SEWER

BY

WILBUR ROY MANOCK

THESIS

FOR THE

DEGREE OF BACHELOR OF SCIENCE

IN

CIVIL ENGINEERING

COLLEGE OF ENGINEERING

UNIVERSITY OF ILLINOIS

PRESENTED JUNE, 1910

UNIVERSITY OF ILLINOIS

COLLEGE OF ENGINEERING.

June 1, 1910

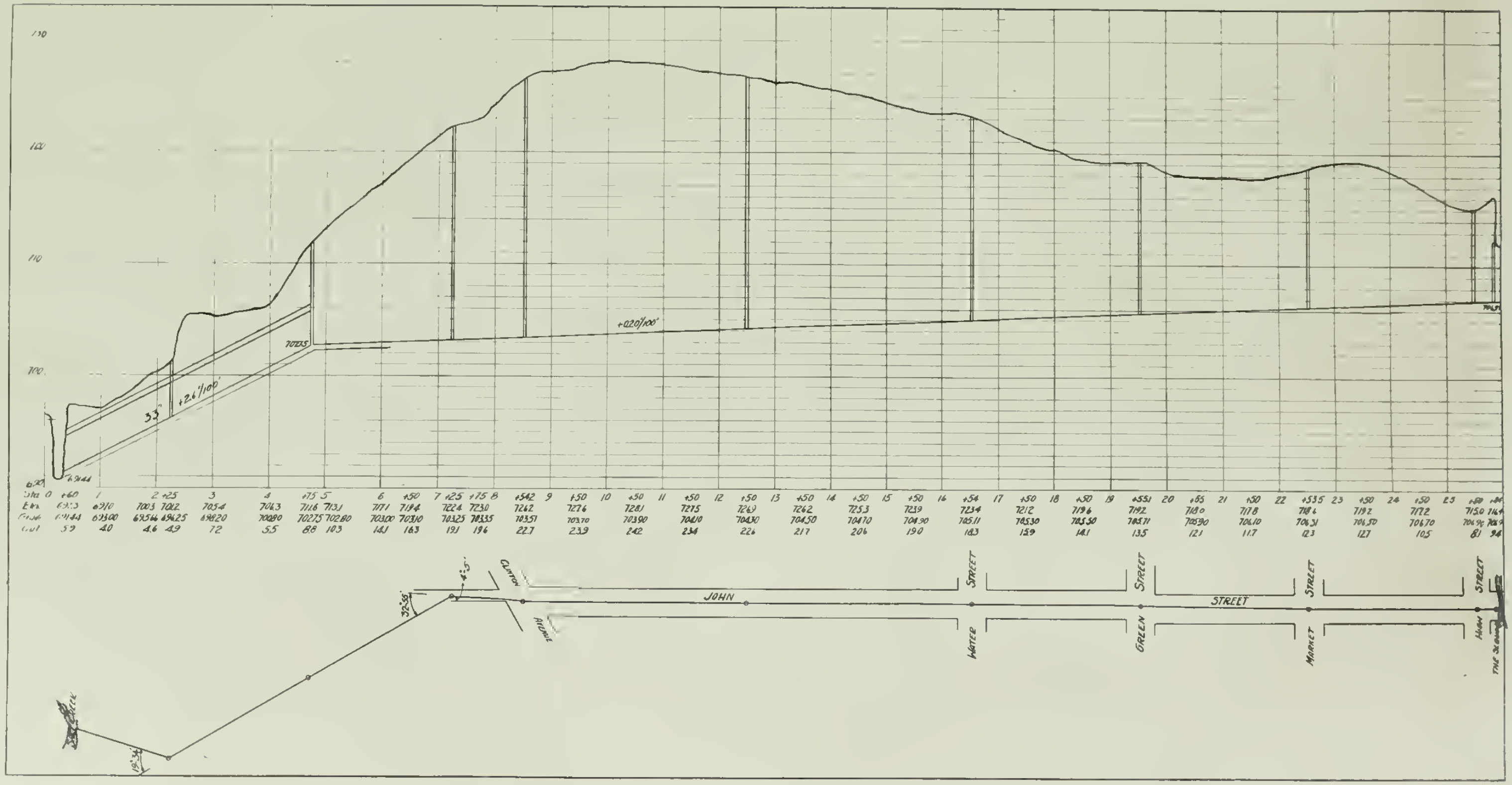
This is to certify that the thesis of WILBUR ROY MANOCK entitled Cost and Methods of Constructing a Concrete Sewer is approved by me as meeting this part of the requirements for the degree of Bachelor of Science in Civil Engineering.

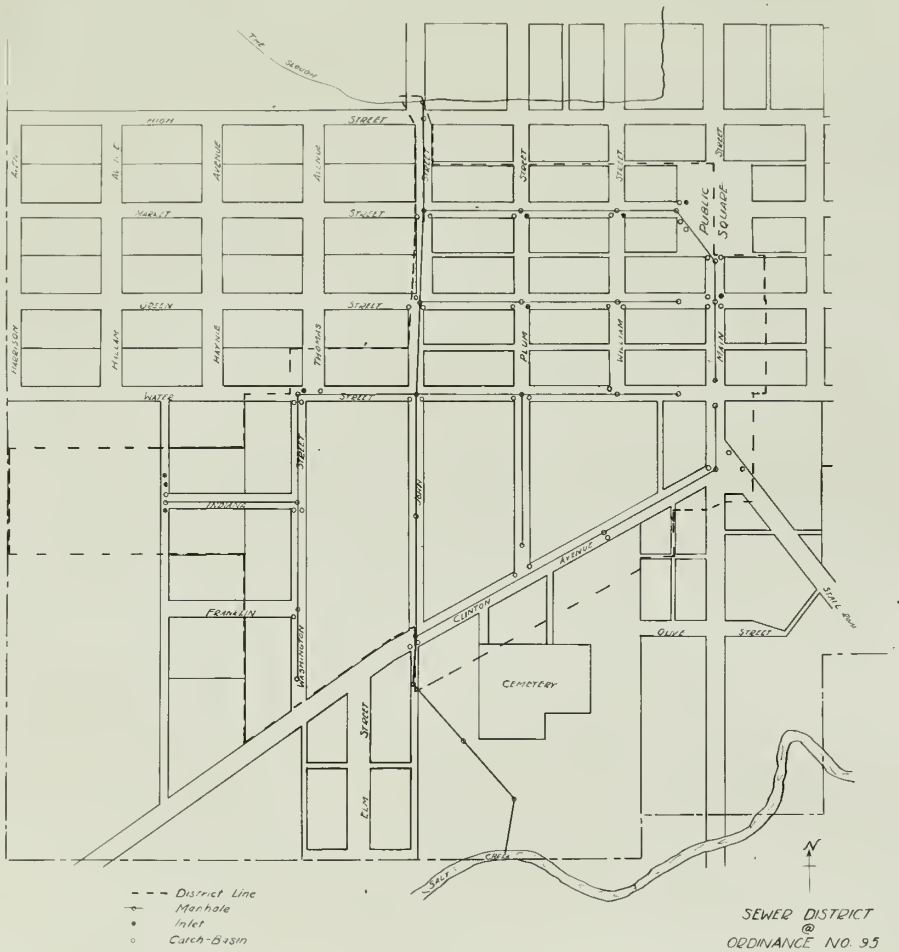
J. Elmo Smith
Instructor in Charge.

Approved:

Ira O. Baker
Professor of Civil Engineering.

C O N T E N T S .


+2.6'/100'
+0.20'/100'
JOHN
STREET
CLINTON
AVENUE
WATER
STREET
GREEN
STREET
MARKET
STREET
MAIN
STREET



SEWER DISTRICT
@
ORDINANCE NO. 95

INTRODUCTION.

A great deal has been written about the methods and cost of construction of municipal improvements, and a great variation is found, both in the methods of construction and in the cost of construction. Some writers advocate that improvements should be let out by contract, while others claim that it is cheaper to have improvements made by day labor. The purpose of this thesis is to describe the methods used in constructing a combined sewer at Farmer City, Ill., which was let out by contract. This sewer was built of concrete and was 33 inches in diameter. The cost of this to the contractor will be shown from cost data which the writer secured while in charge of the construction.

Article 1. Plans and Profiles.

The plans, under which the sewer was constructed, were drawn by the City Engineer. In preparing these plans a complete topographic survey of the city was made. After a careful consideration of this survey, it was decided to have the outlet of the whole system at Salt Creek, near the southwestern part of the city. The system was so planned that one part, or district, could be constructed independently of the remainder, after a short section at the outlet had been constructed. The 33 inch sewer under consideration is the outlet of the entire system and the main sewer of the district in the southwestern part of town. It is 2585 feet long and extends northward from Salt Creek to a small branch of this creek called The Slough. The sewer was constructed of monolithic concrete and has a circular section 33 inches in diameter. The thickness

of wall specified was 6 inches. Fig. 1 shows the actual section used in solid material and Fig. 2 the section used in soft material.

From the profile, which was taken from the original survey made by the City Engineer, it is seen that the depth of cut ranged from 3 to 10 feet in the first 500 feet, and that it rapidly became greater until at Station 10, it was about 25 feet. It is also seen that from here the depth gradually became less until at the end it was about 9 feet. All depths of cuts are figured to the inside bottom of the sewer barrel. Owing to a slight change in the alignment near the outlet, 60 feet was cut off the original length. This puts the actual zero at Station 0 + 60 of the original profile.

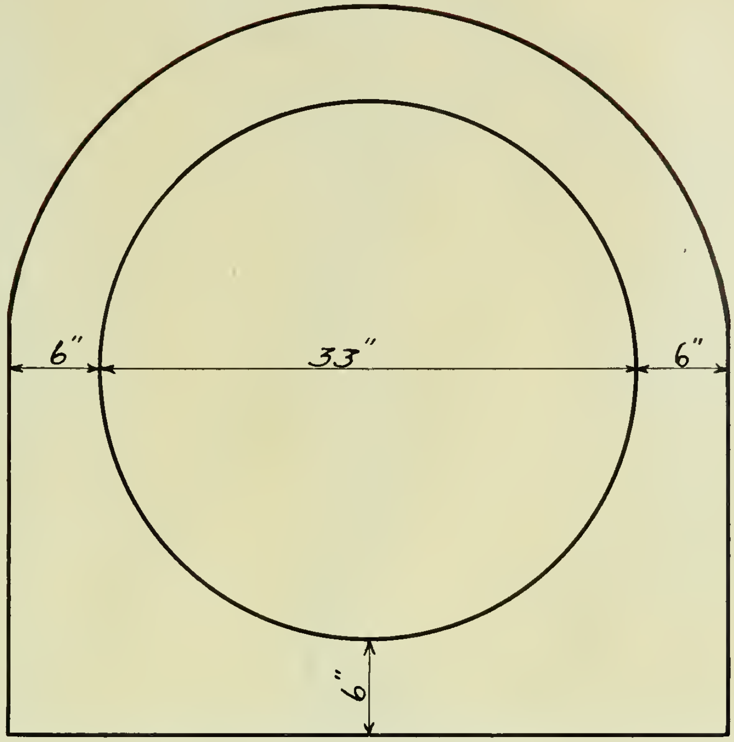
A retaining wall, containing 15 cu. yds. of concrete was built at the outlet. This wall extended down 5 feet below the invert of the sewer. The wing walls were about 8 feet long and extended down to the same depth as the main wall. It was the original plan to have a similar wall at the upper end of the sewer, but when the construction reached that point the city council decided to put in a concrete bridge and to use one of the bridge abutments as a retaining wall. The contractor was then allowed to put the 15 cu. yds. of concrete into the bridge abutment instead of building a retaining wall. A sluice-gate was attached to the bridge abutment as shown in Fig. 3.

Article 2. Materials Used In Construction.

Cement.

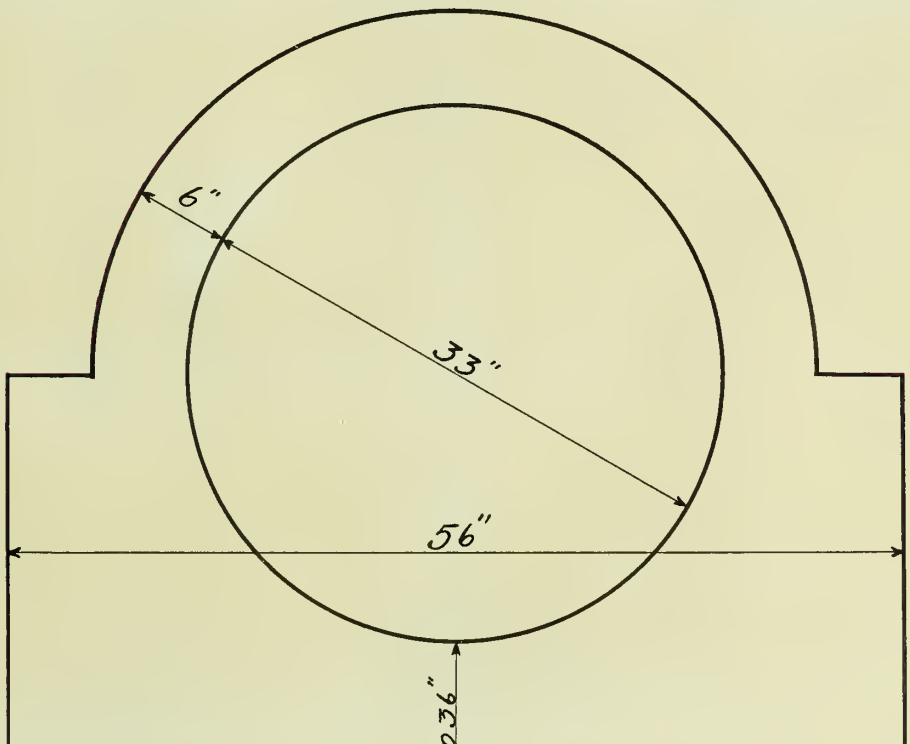
The cement used during the greater part

Fig. 1



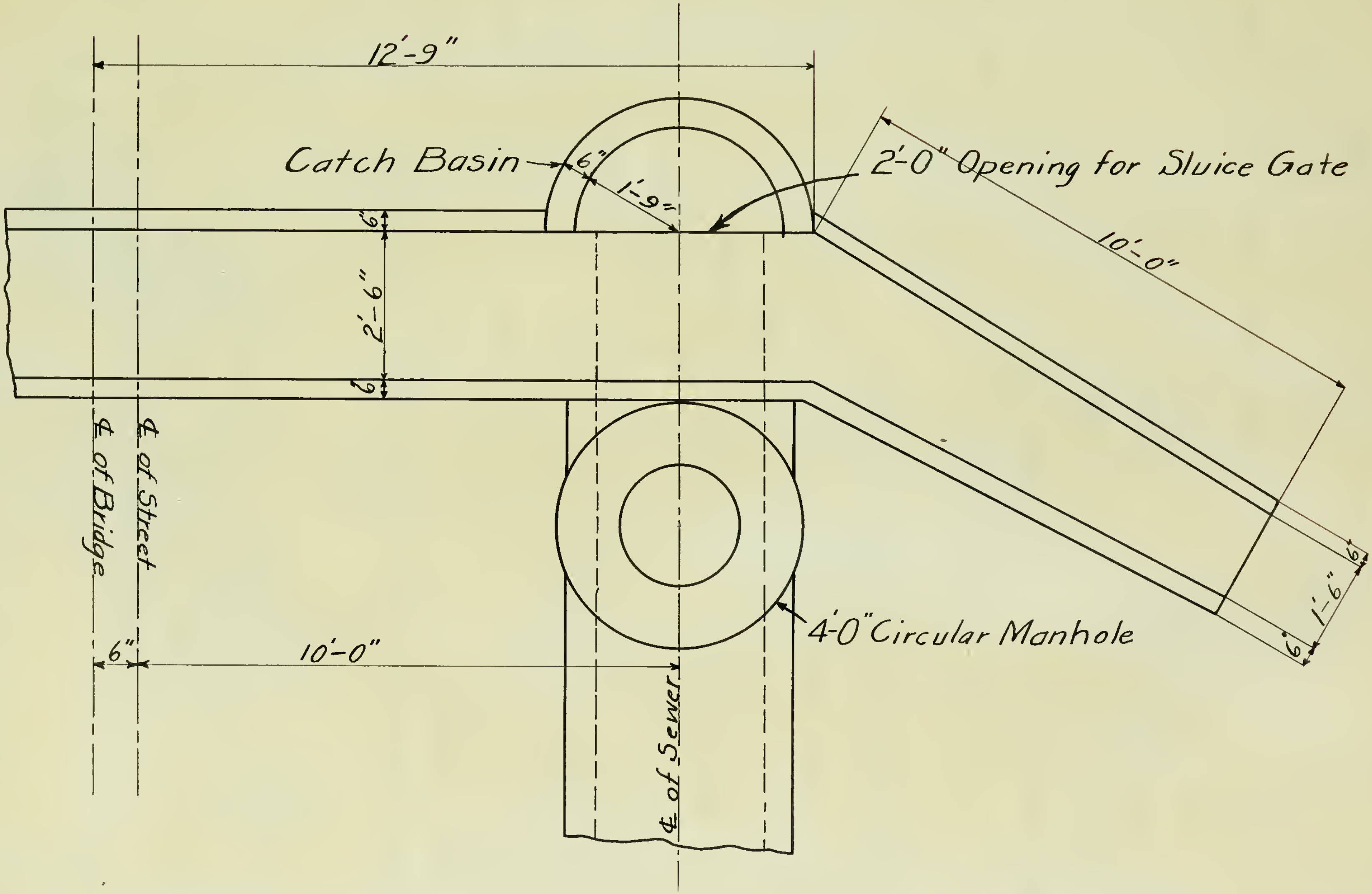
Ordinary Section

Fig. 2



Section used in soft materials

FIG. 3



Intersection of Sewer with Bridge Abutment.

of the construction was Medusa Portland, made by the Sandusky Portland Cement Co. Tests made from samples sent to the Testing Laboratory at the University of Illinois showed that this cement complied with the Standard Specifications advised by the Committee of the American Society for Testing Materials. At times the dealer would run short of Medusa cement and at such times the Owl Portland cement, manufactured by the German-American Portland Cement Co. was used. In tests, this cement also complied with the specifications above mentioned.

Sand and Gravel.

The sand and gravel used was obtained from a sand bank near the northern part of the city. No laboratory test of the sand and gravel was made, but it contained a large amount of clay. As a rule, this did not amount to more than 10 to 15 per cent.

A large amount of fine, white sand and gravel was encountered during the course of excavation. The contractor wished to use this as aggregate for the concrete. By experiment, it was found that the concrete made from this material was of very poor quality and the contractor was not permitted to use it.

Water.

The water necessary to run all excavating machinery and to make concrete was furnished free of charge by the City. This was specified in the contract.

Lumber and Brick.

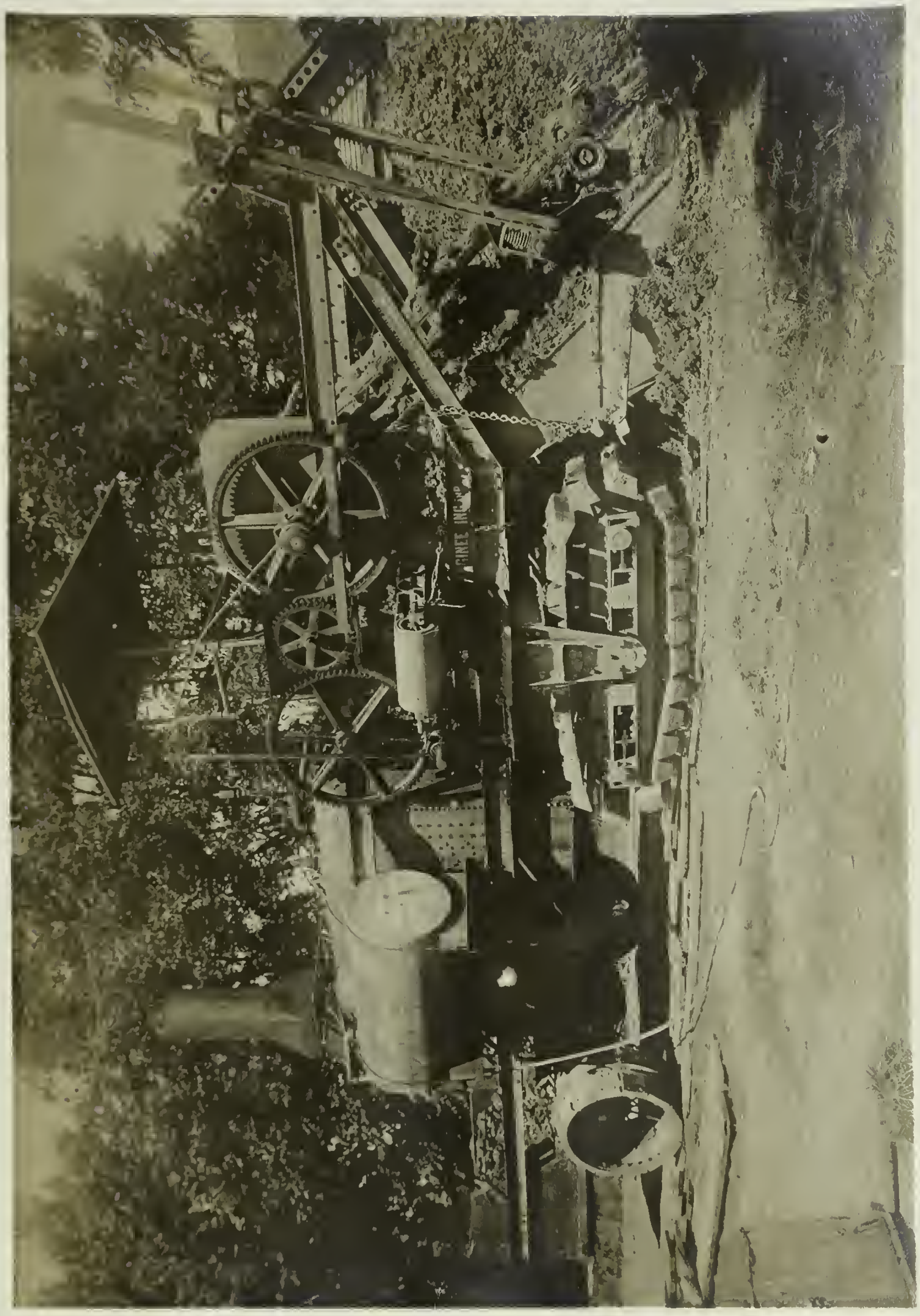
The lumber used for sheathing the trench, and the brick used in the manholes and catch-basins

were purchased of local dealers. They were delivered upon the work by the dealers.

Article 3. Method of Excavation.

The character of the soil and the large amount of ground water added a great many difficulties to the work. The top layer of soil was the black Illinois prairie soil. This was underlaid by a layer of what was known locally as "block clay". As its name signifies, this soil after being exposed to the air for a while, would crack and cave off in large blocks or cubes. At a depth of about 12 to 15 feet, pockets of quick-sand were found. These were always signalled by a large amount of running ground water. In the deepest cutting these pockets came high enough above the bottom so that they ~~were~~ partially held in check by the sheathing. However, in the shallower digging, these pockets were just about at the height of the bottom of the trench and thus gave much trouble. The only method by which the quick-sand could be handled and the trench kept open long enough to get the concrete in place was to drive sheathing down two or three feet below grade. Then the sheathing was made water-tight by putting straw in the cracks. This was a very slow process and required that a close watch be kept upon the sheathing so that the sand could not get started through at any point.

The excavation was nearly all done by machinery. About 400 lineal feet was excavated by hand because the contractor was anxious to get the work started on time and it was not possible to get the machine on the work. The Municipal Engineering and Contracting Co., of Chicago, leased one of



of their large excavating machines, The Chicago Excavator, to the contractor. This machine is best described by the cut. The engine had a 70 H. P. boiler and carried its own water-tank and coal box. The excavating tail consisted of a continous chain with a special bucket attached every 4 or 5 feet. This tail was quickly raised or lowered by special gearing so arranged that it could be operated from the cab or top of the machine. The machine was built to excavate a trench with a maximum width of 5 feet and 20 feet deep. However, on this contract, the machine dug successfully a trench that was over 25 feet deep. The best performance of the machine was on July 2, 1909, when it dug 60 feet of trench 25 feet in depth in two hours actual running time. In ten-foot digging the machine made a run of 350 feet in 4 hours of actual running time. In both cases above mentioned time was taken out for sheathing the trench. In 20-foot digging the machine would run for 5 minutes and then it would stop for 7 minutes while the trench was sheathed. This was average time for several days test. At all times, irrespective of the soil, the machine could excavate faster than the trench could be sheathed. Especially, was this true in the softer material. Here the machine was of the least advantage, in fact, it worked at a disadvantage because the action of the excavating chain and buckets would churn the soft material and thus cause the banks to cave before they could be held with the sheathing. The method finally adopted on the part of the construction where the quick-sand was found, was to take only the top 8 or 10 feet off with the machine and then excavate the remainder by hand.

In clay banks, though, this machine was efficient, and with good management of the men should have excavated the trench at a low cost.

Two methods of bracing the trench were used. Fig. 4 shows the one used when soft material was encountered while using the machine. 2" x 12" planks were used for the sheathing and these were placed parallel to the slope of the excavator chain. They were put opposite each other and were put in place as quickly as possible after the machine had moved forward. Care was taken that the jacks were placed at right angles to the bank so that they could better withstand the enormous pressure that was brought upon them. In the deep cut it was necessary to use two 14 foot lengths. Three jacks to each pair of planks were first put in and then when 16 feet of trench had been opened, heavy rangers were put in as shown in Fig. 5. Then the first jacks were removed. Where good banks were encountered a different method was adopted. It was not safe to leave the banks unprotected, so just enough sheathing was put in to keep the banks in place. Then the boards were placed vertical and spaced a bout a foot apart. These were held at first by jacks, which were removed after the rangers had been placed. This method was not used successfully where the cut was over 15 feet deep.

The method used to maintain the alignment of the trench was very simple. Before work was started upon each block the center line of the proposed sewer was laid out. A parallel line about ten feet distant was then staked out with hubs every 25 feet. From these hubs a line was so set that

Fig. 4

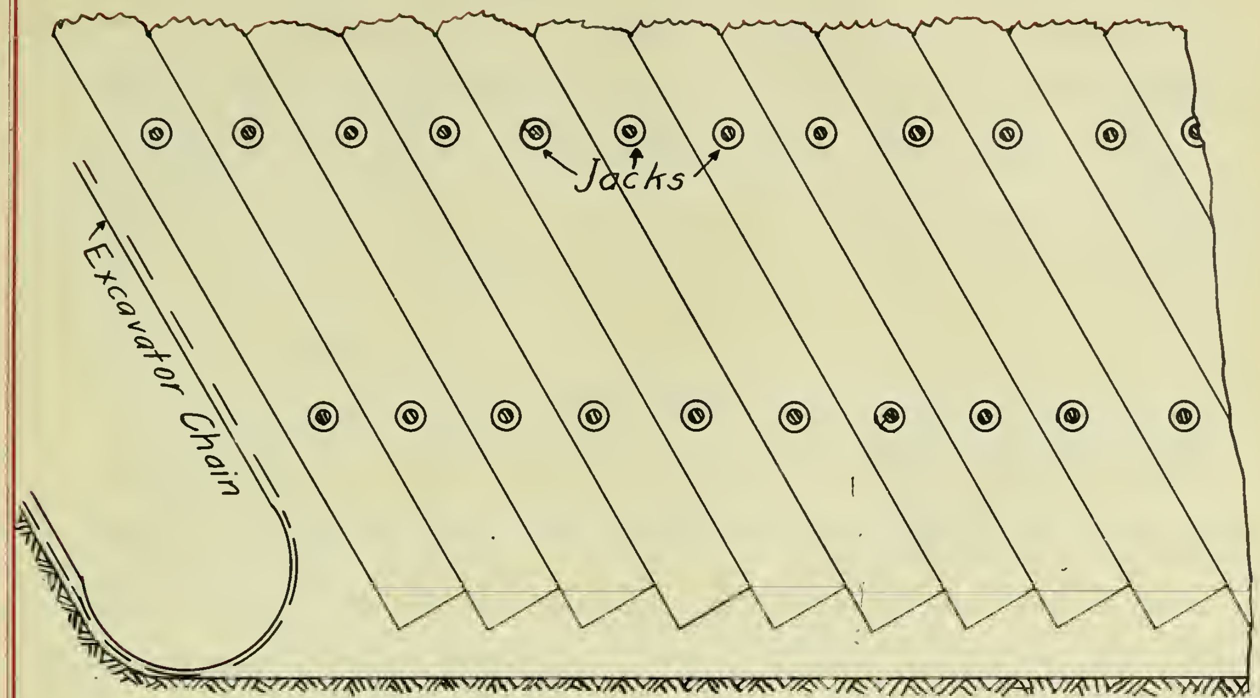
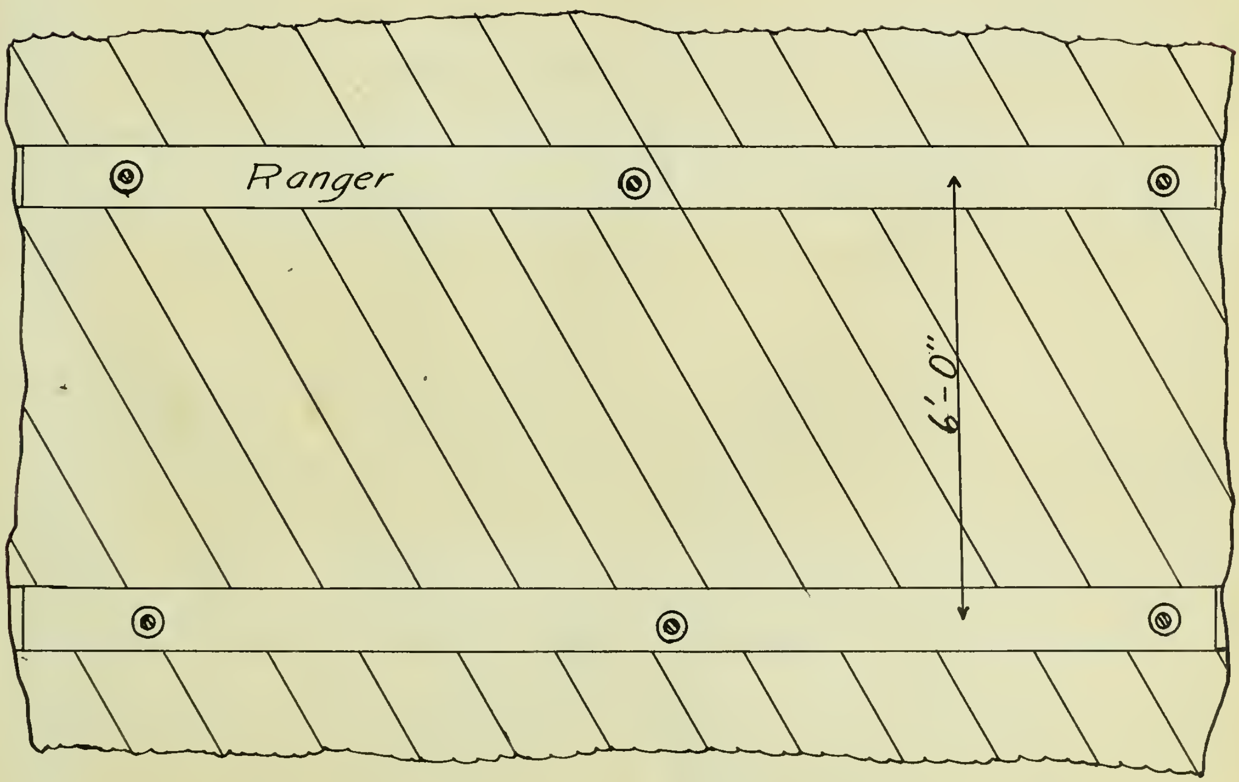


Fig. 5



a pointer on the front wheel of the machine would be exactly over the string when the excavator was in the proper place. The machine was guided by the engineer and thus the trench was correctly aligned. In the deep digging the front of the machine tended to tip up and thus it was difficult to maintain the alignment. By keeping the coal box full this difficulty was overcome.

Where good banks were found, and where there was not enough water in the trench to interfere with the concrete work, the method of operation used was to start the excavator the first thing in the morning and open up as much trench as it was thought desirable. This would amount to about 65 feet, and would probably take until noon. Then at noon the men would start to get forms for the concrete and proceed to place the concrete. For a greater part of the distance, though, it was only possible to open up one form length or 16 feet at once. Then the work had to be rushed to get the concrete in before the sand and water got the better of the workmen. The sand was kept out of the trench by tight bulkheads driven down about 3 feet below the grade of the trench.

Article 4. Method of Making and Placing Concréte.

As soon as possible after the trench had been excavated, the invert form was placed in position and the concrete put in the form. The forms used for the invert were wooden, semi-circular, and 16 feet long. They were in three pieces, so arranged that they fitted snugly together, especially when wet. The part marked (b) in Fig. 6, was first placed in the

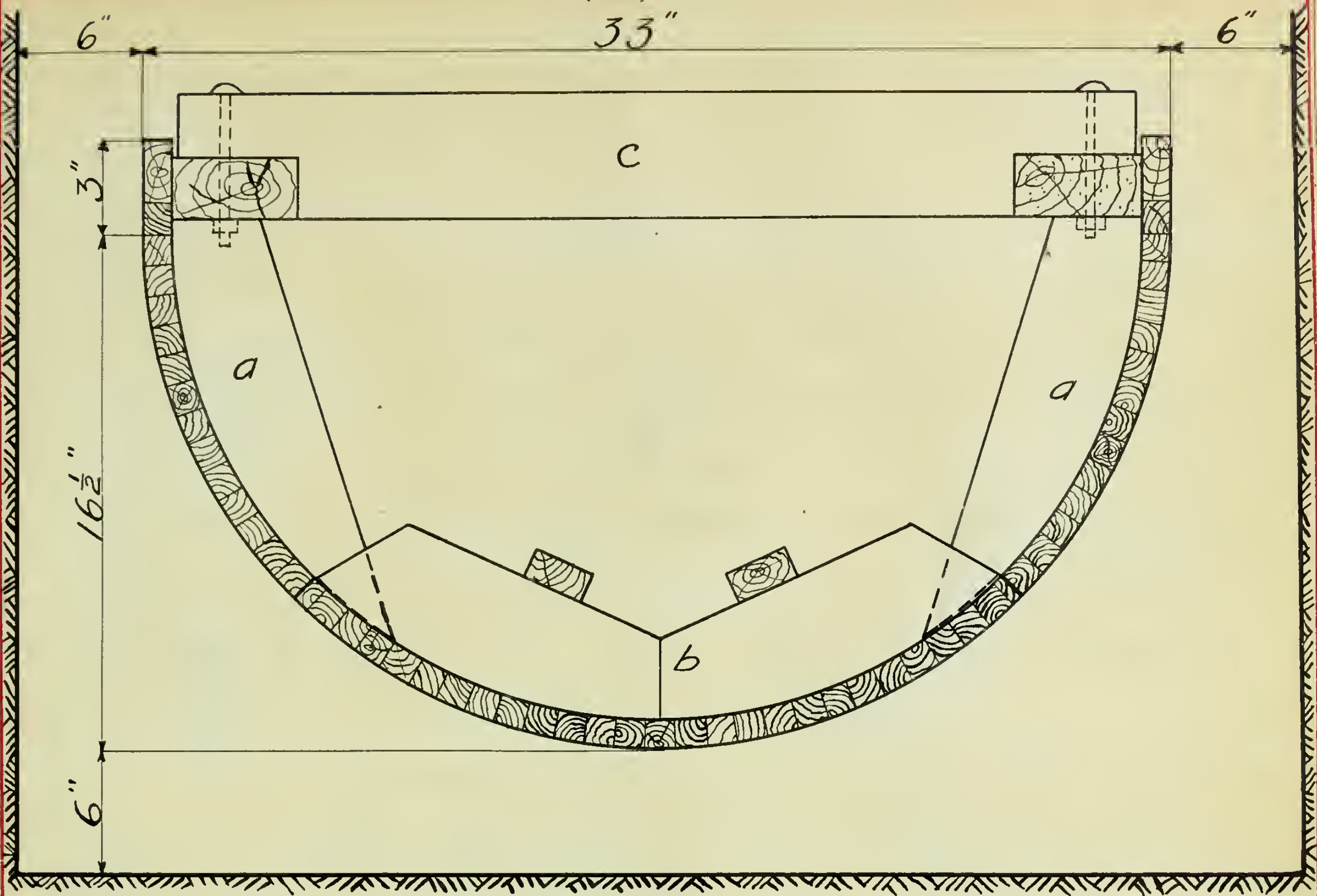

6"
33"
6"
3"
c
a
a
$16\frac{1}{2}$"
b
6"

FIG. 6

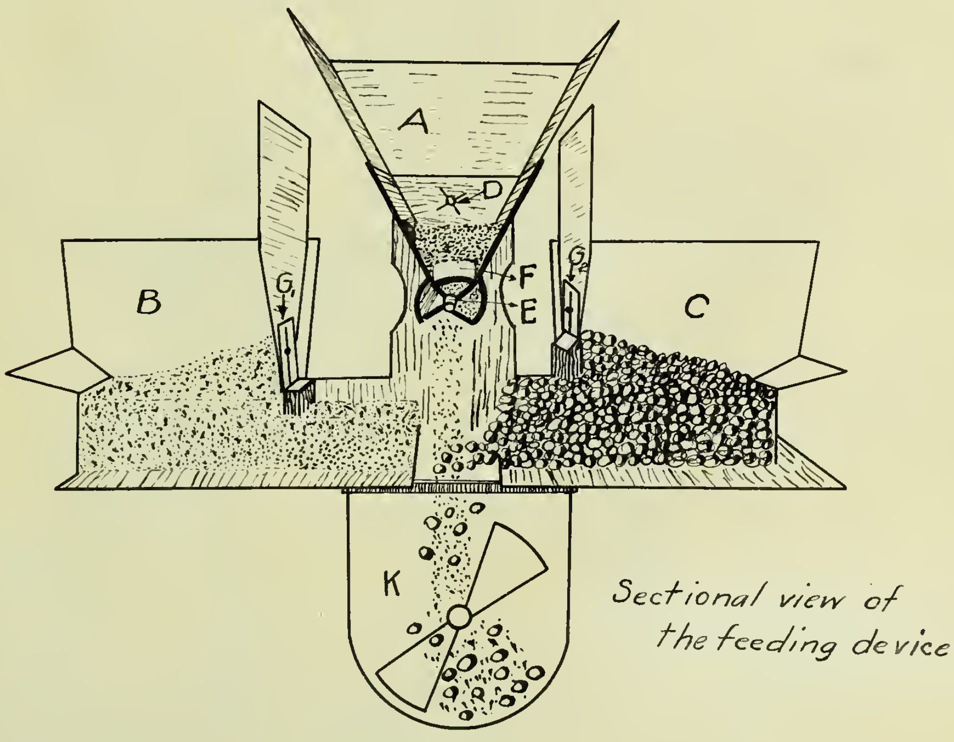
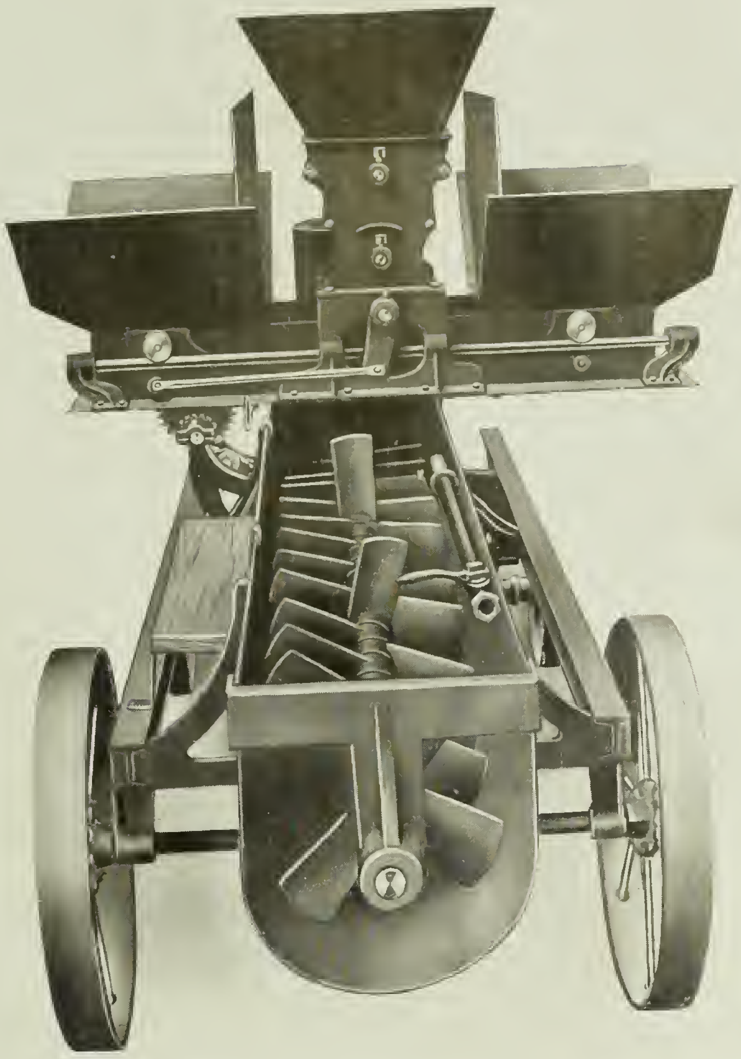

A
D
B
G_1
F
E
G_2
C
K
Sectional view of the feeding device

FIG. 7

trench and the ends supported at the proper height by means of brick placed under them. Then, the two parts (a, were put in place carefully, and the whole form carefully levelled up and fastened in position by cross-arms (c, and strips nailed to the forms and extending against the banks or sheathing. The end was closed up by a water-tight bulk-head of boards. The concrete was mixed upon the bank and sent down a chute or spout to the bottom of the trench. A wet mixture was used for the invert. Two men were in the bottom. One handled the chute and the other, with a spade, made sure that the ends and bottom of the form were properly filled.

The forms used for the crown of the sewer were the "Blaw Collapsible Steel" centers. In the ordinary running these forms were drawn ahead from the crown put on last. In this way only a comparatively small number of forms were put into the trench at once. The forms were 5 feet in length, but were so arranged that any number of forms could be fastened together and thus drawn along at one time. These forms were collapsed by means of a turn-buckle at each end. Rollers in these turn-buckles rested on a wooden track and thus the forms were easily moved forward.

When in the new position the turn-buckles were loosened and the form blocked up so that with the invert already in place, a full circle 33 inches in diameter was formed. Then the concrete was let down through a spout, as it was for the invert. In this case, however, a dry mixture was used. The concrete was spread evenly over the form, the depth being tested by means of a small round gauge stick of the proper



THE "GRAND"

length. About 15 feet of crown was put in at one setting of the machine. It took the same number of men in the trench as for the invert.

The concrete was mixed in the Grand Concrete Continous Mixer , manufactured by the Hall-Holmes Manufacturing Co. of Jackson, Mich. This mixer had a large hopper (A) on the top into which the cement was poured. The cement was admitted to the mixing chamber by means of a slide (EF) at the bottom of the hopper. This slide could be regulated so as to give any proportioned concrete. On each side of the large hopper was a smaller one (B and C) into which sand and gravel were shovelled during the process of mixing. The amount of each of the aggregate that was pushed into the mixing chamber at one time could also be regulated by means of brushes (G_1 and G_2). The mixing chamber (K) was of the single shaft "Pug Mill" type. Here the cement and the aggregate were partially mixed before the water was added to them. This is one quality that is necessary for a continous mixer if it is to be successful. The mixing was always in full view of the operator and the supply of water was also controlled by him.

The mixer is operated by means of a 2 1/2 H. P. gas engine that is on the front end of the truck but is not visible in the photograph. In order to properly operate this mixer, 4 men were necessary. One man stood on a platform and emptied the cement into the hopper and watched that the measuring device was always working properly.One man handled the cement from the store-house to the mixer and handed it to the operator on top. Two men were used to shovel the sand and gravel.

When gravel alone was used both men shoveled into the same hopper.

The average time necessary to mix and place concrete in a sixteen foot invert form was 28 minutes. This time was figured on the basis of making one setting for each sixteen feet of form, but does not include the time used in stopping the machine and moving it to the next position where it had to be blocked up level for operation. This took from 20 to 30 minutes, depending upon the amount of blocking necessary to get the mixer to set level or with the front wheels a little higher than the rear ones. A method at first used upon the work to avoid the delay in moving the mixer, was to lay a broad track lengthwise over the ditch and run the mixer over the trench. All that was necessary for another set-up was to pull the mixer ahead the required distance. This took practically very little time. However, as a rule, the sheathing stood up higher than the surface of the ground so this method could not be used. A great deal of time would have been saved if the last mentioned method had been used on the entire work.

In the case of the crown it took only 24 minutes to make and place the concrete upon a 16 foot form. The men in the bottom could handle the concrete faster with crown forms than with the invert forms.

The forms had to be left in place for 20 to 24 hours after the concrete had been placed. Thus, if the invert was put in one afternoon the form would be taken out the next afternoon and the crown put on. Then the crown form could not be pulled until the next afternoon.

Article 5. Cost.

The cost data given in this thesis was obtained by the writer while employed upon the work as assistant engineer for the city. The writer had access to the books of the contractors, and the prices quoted for materials and labor are the actual prices paid.

The discussion of the cost of this sewer will be divided into two parts; first, the cost of the concrete in place, and second, the cost of excavation.

(1). Cost of Concrete in Place.

The concrete used upon all of the work consisted of approximately one part of Portland cement to five parts of sand and gravel by volume. The gravel cost, delivered upon the work, $1.00 per yard. It was hauled alongside the trench and dumped at the proper distance from it for the men to shovel it easily into the mixer. The cement used, cost, delivered upon the work, $1.20 per bbl. net. No large amount of cement was stored upon the work at once. Usually only sufficient for a days run was kept there.

From tables in Baker's "Treatise on Masonry Construction" one cubic yard of concrete of the proportions 1 to 5 should require 1.61 bbls. of cement and 1.13 cubic yards of sand and gravel. Using these figures and the costs given above, one cubic yard of concrete should cost $3.06. The total area of the sewer barrel of the ordinary section used was 3.52 square feet. Thus, one cubic yard of concrete made 7.64 lineal feet of sewer. Taking this value. then, one

TOTAL COST OF CONCRETE IN PLACE

Items of Cost	No. of Men	Time Minutes	Price per hour	Cost per 16 feet	Cost per lineal foot
Materials					$0.540
Labor-mixing	6	52	$0.25	$1.30	0.083
" -invert forms	3	45	"	0.57	0.036
" -Crown "	3	25	"	0.69	0.043
" -moving mixer	3	25	"	0.32	0.020
Supertendence		177	$0.50	1.50	0.094
Total					$0.816

lineal foot of sewer would cost $0.40 for materials alone. Upon checking up the actual amount of materials used, it was found that the actual amount was 36 percent greater than the theoretical amount as figured above. Thus the actual cost for materials was $0.54 per lineal foot. This seems to the writer to be very close because the actual amounts include all materials that were delivered upon the work and so the various losses due to unavoidable carelessness upon work of this kind were included. Then, also, a large amount of this difference could be found in the excavation of the trench itself. The workmen were not always careful to trim up the bottom and sides exactly to neat lines. They worked upon the theory that it was easier to take off a thicker layer of earth and be sure to have the trench deep enough than to take off several thinner layers.

In the table showing the total cost of the concrete in place, the cost of labor was figured out from the actual average time spent upon a section form 16 feet long. In this table no allowance has been made for the wear and tear upon the mixer and tools used and for the rent of the crown forms. In this respect the data is not complete, but otherwise it is as accurate as it is possible to obtain.

(2). Cost of Excavation.

The cost of excavation per lineal foot was harder to calculate than the cost of the concrete. Conditions varied so much, the character of the soil excavated changed so rapidly, and the personnel of the organization shifted so often that it was almost impossible to reduce the cost to a

satisfactory basis. However, there are a few items of cost that may be considered fixed, and these will be mentioned first.

The excavating machine was leased for the construction of both the main sewer and the laterals for a fixed sum of $2,700.00. The freight on the machine from Chicago to Farmer City was $154.75. This makes the machine cost $2854.75 F. O. B. Farmer City. The estimated cost of the main sewer was $7850.00, which was 54.6 per cent of the total estimated contract for which the machine was leased. 54.6 percent of the cost of the machine is $1560.00, which is the portion of the whole charged to the main sewer. Since there was 2100 feet of trench excavated by the machine, the amount charged to the machine was $0.74 per lineal foot.

The average amount of coal used by the machine per lineal foot of trench was 55 lbs. This coal was delivered upon the work for an average price of $3.00 per ton. Thus, the cost per lineal foot for coal was $0.08.

The lumber bought for sheathing and other purposes amounted to $2050.70. Part of this lumber was entirely destroyed or was left in the trench by order of the engineer. For this last mentioned lumber the contractor received extra renumeration, and so it will not be charged against the work. As near as it is possible to determine, one half of the cost of the lumber should be charged to the main sewer. This was not used uniformly along the entire trench, but about the only method of procedure possible is to distribute the cost uniformly. This makes the cost $0.40 per lineal foot for lumber.

Summing up the above, we get the following as a fixed cost per lineal foot of trench:

Rent of Machine,	$0.74
Coal for Machine,	0.08
Lumber,	0.40
Total,	1.22

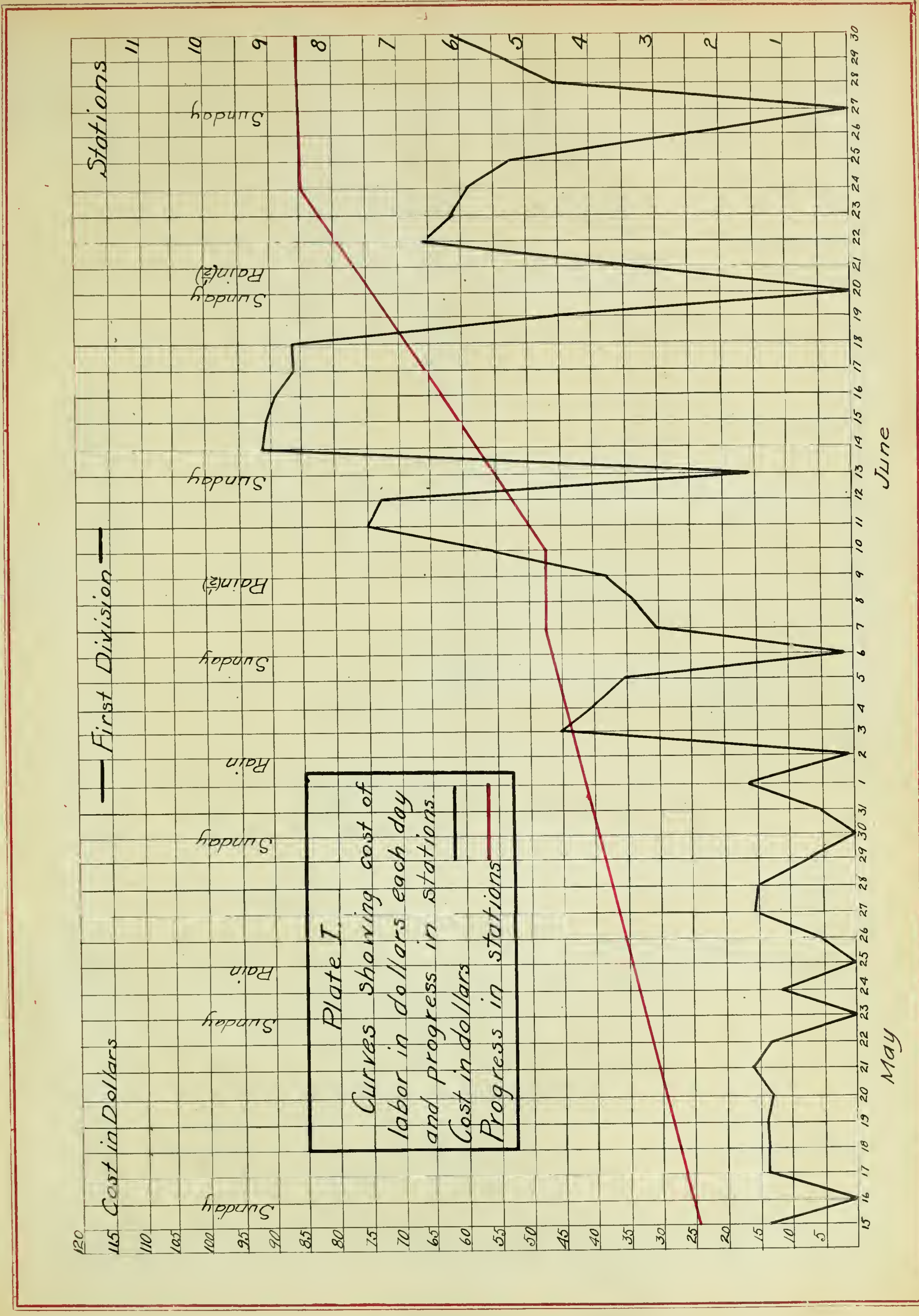
In order to discuss the cost of excavation, the sewer will be divided into three parts. The first part extends from the outlet to the intersection of Clinton Avenue and John Street, and is 854 feet long. This division may be called the division of easy cutting. There were no unusual difficulties and the cutting was not over 10 feet deep. This was the division upon which the contractor could best make his profits.

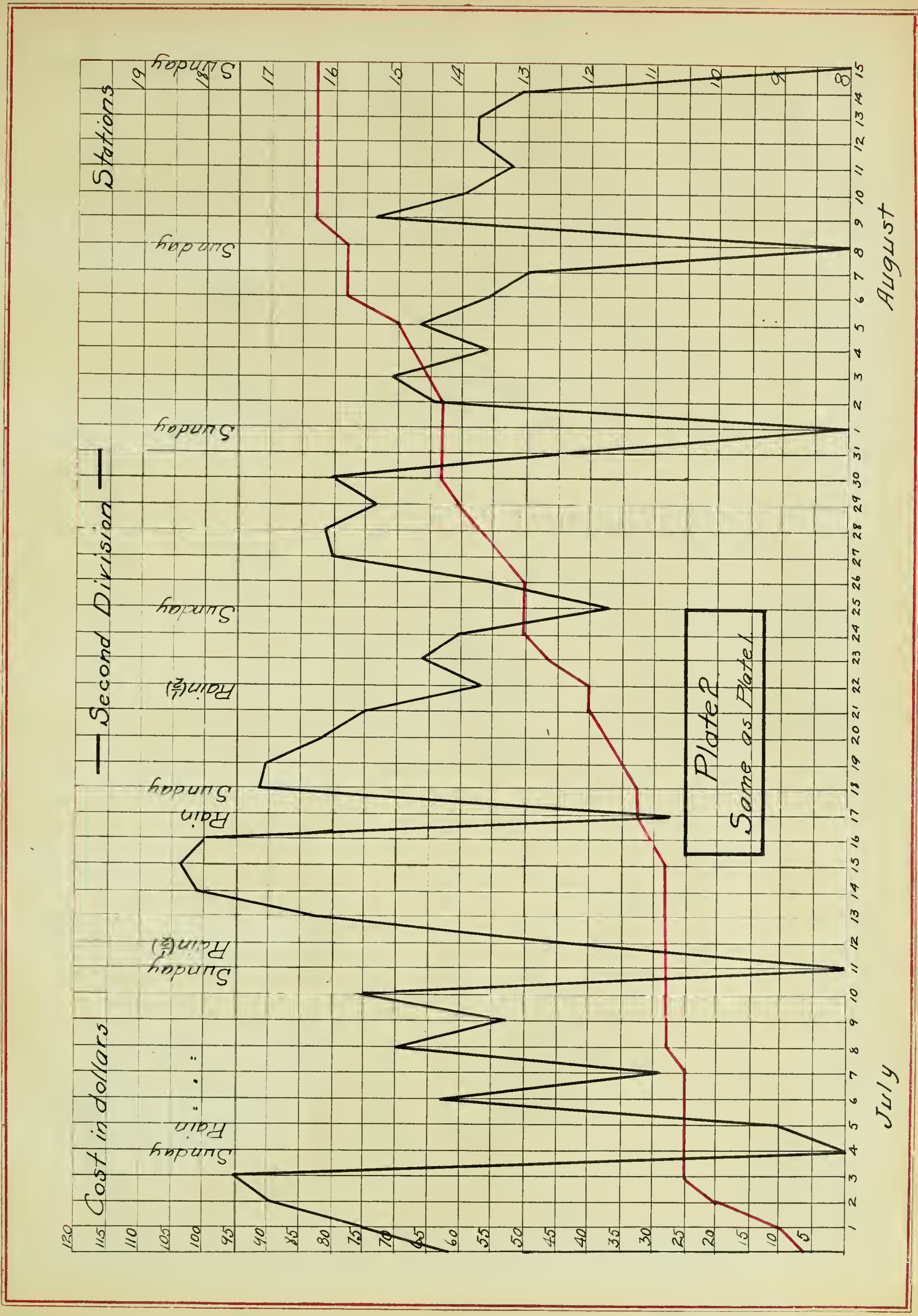
The second division extends from Clinton Avenue to Water Street along ~~on~~ John Street. This section was 800 feet long and contained the deep cutting. The average cut was 21.6 feet. This division was one of great difficulty to the contractor. Besides the natural difficulty of working in such a deep trench and the large amount of sheathing necessary to properly brace the banks, mismanagement increased the cost a very great amount. One instance will tend to show this more clearly. Near Station 10, in the deepest cut of the work, a long section of the trench was allowed to stand open for 5 days before the sewer was laid. During this time, there were three days of rain, and as a result about 60 feet of the banks caved in. Of course, this had to be excavated the second time by hand.

It cost the contractor $465.00 to get the trench opened up again, and besides this, the contractor had to pay $50.00 damages for dumping the extra dirt upon the lawns near the cave in. The opening was about 15 feet wide when the banks had been trimmed enough for bracing. The back filling was also very much greater than it would have been otherwise. Although this was an example of the greatest difficulty encountered, the progress of the construction of this section was greatly hindered and the cost greatly increased by the combination of unusual difficulties.

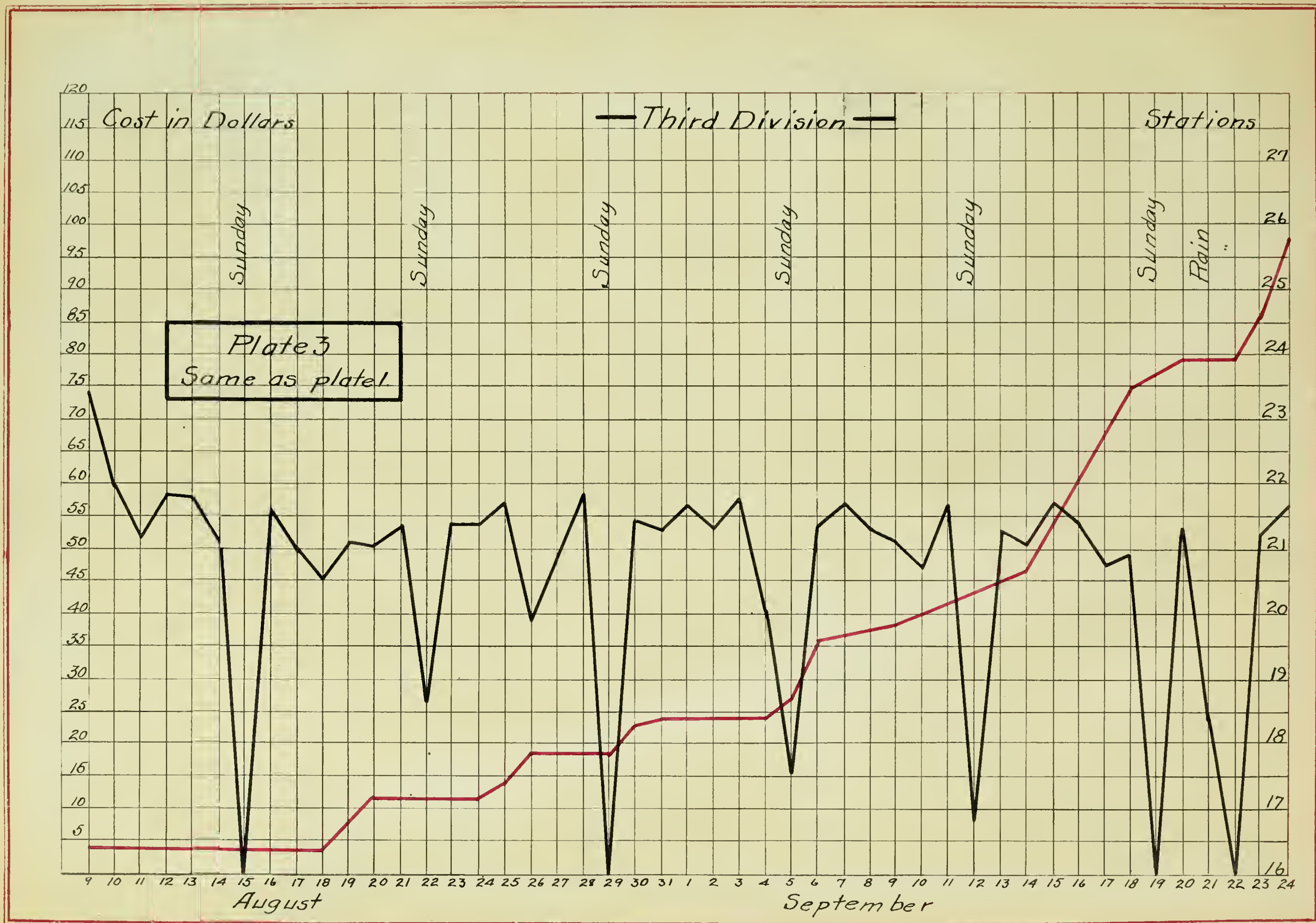
The third division extends from Water Street, 935 feet to the end of the main sewer. In this section a large amount of quick-sand accompanied by a considerable amount of water, was found. The quick-sand was in pockets and whenever one of these pockets was struck, only the top 8 or 10 feet was excavated by the machine and the remainder had to be excavated by hand. This, of course, increased the cost materially. However, the last 400 feet offered no unusual difficulty and the contractor partly made up his loss sustained upon the other part of the work.

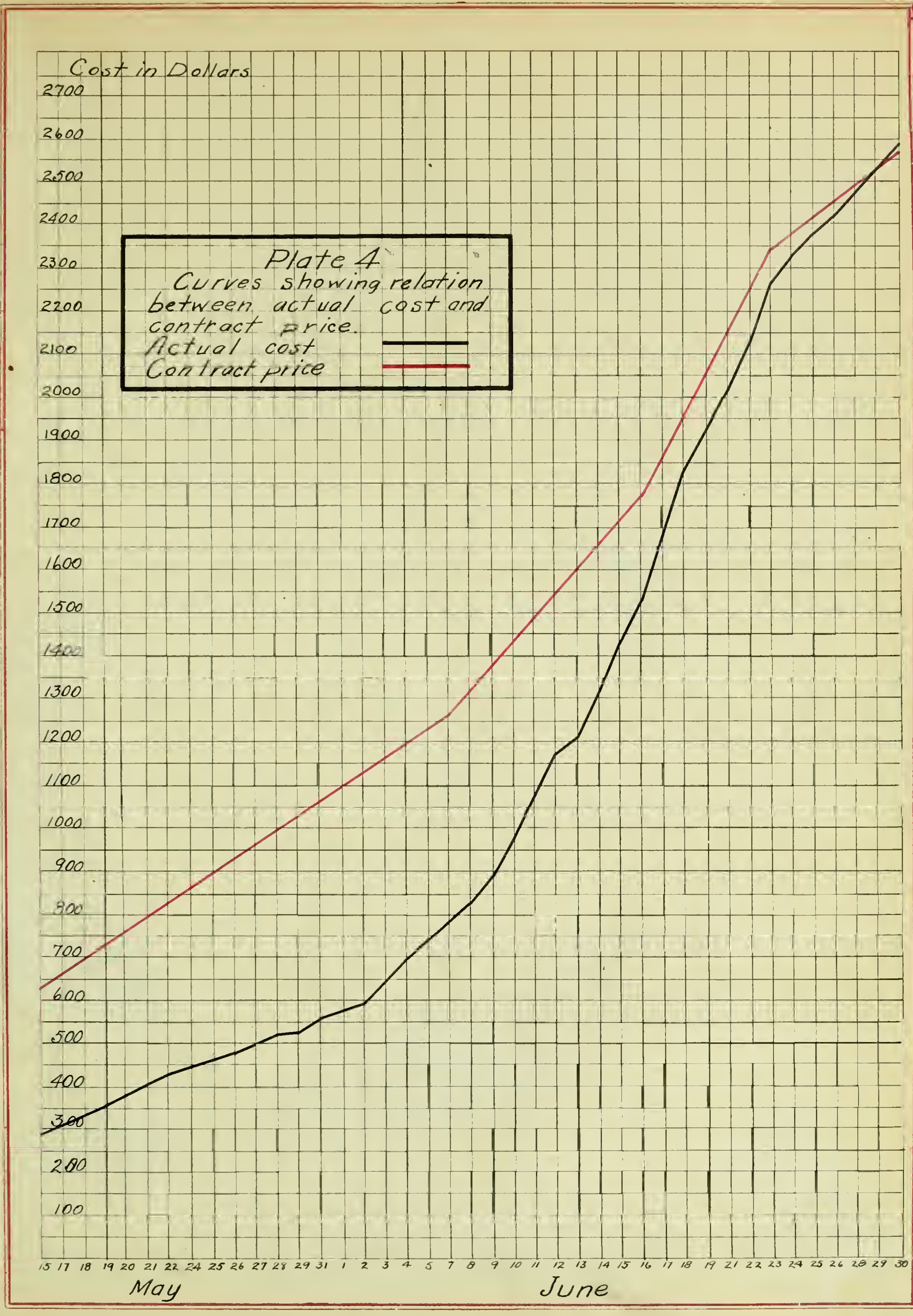
In plates 1, 2 and 3, the daily cost of labor is shown in black. Each plate takes up one division above mentioned. The red line in these plates shows the progress of the work in stations. The date of the completion of the sections of the sewer barrel was kept, and from these notes, the progress curve was plotted. When the red line becomes horizontal, it indicates that no advancement was made on the sewer barrel

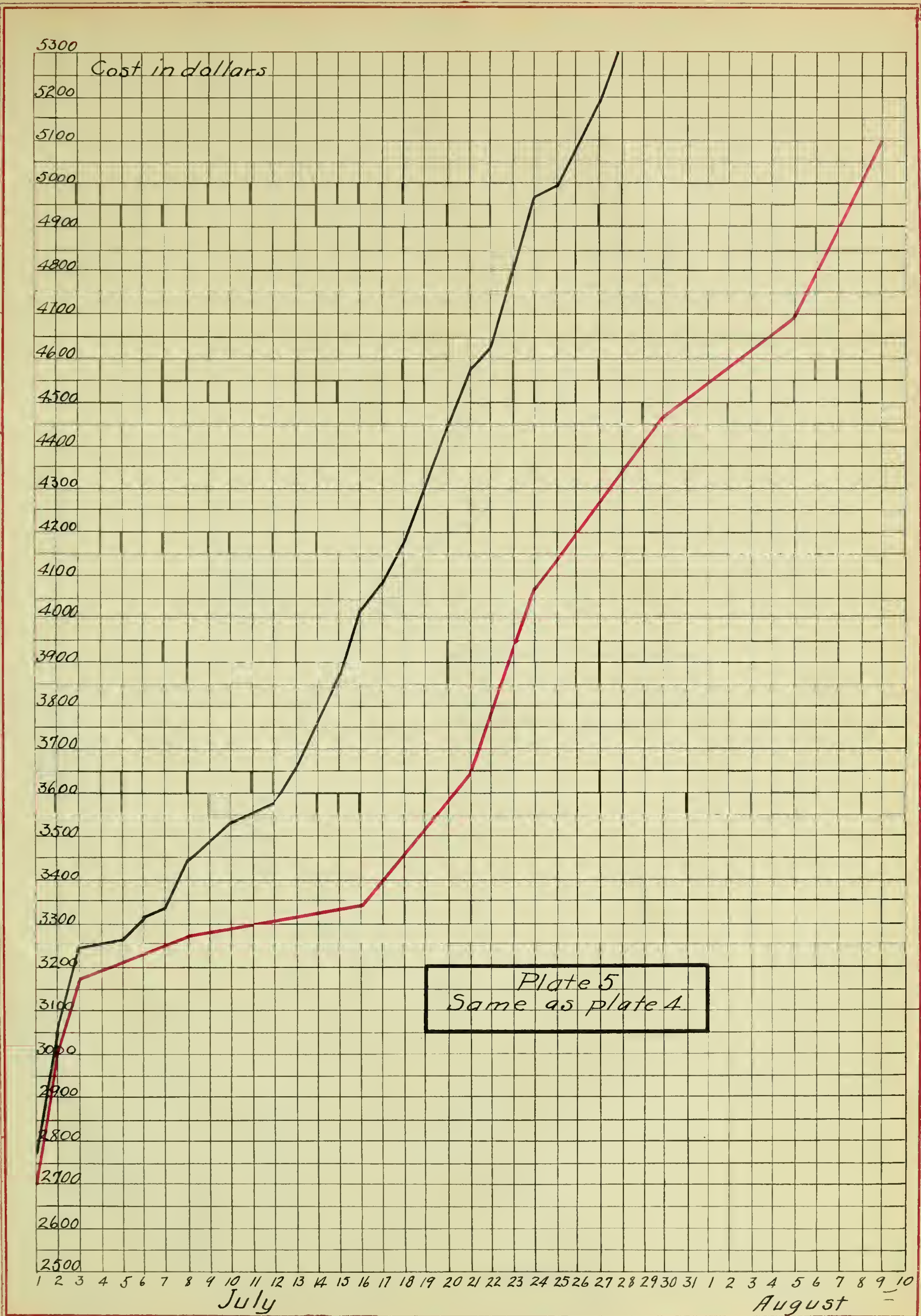

First Division
Cost in Dollars
Stations
Plate I.
Curves Showing cost of labor in dollars each day and progress in stations.
Cost in dollars
Progress in stations
Sunday
Rain
Rain(½)
May
June

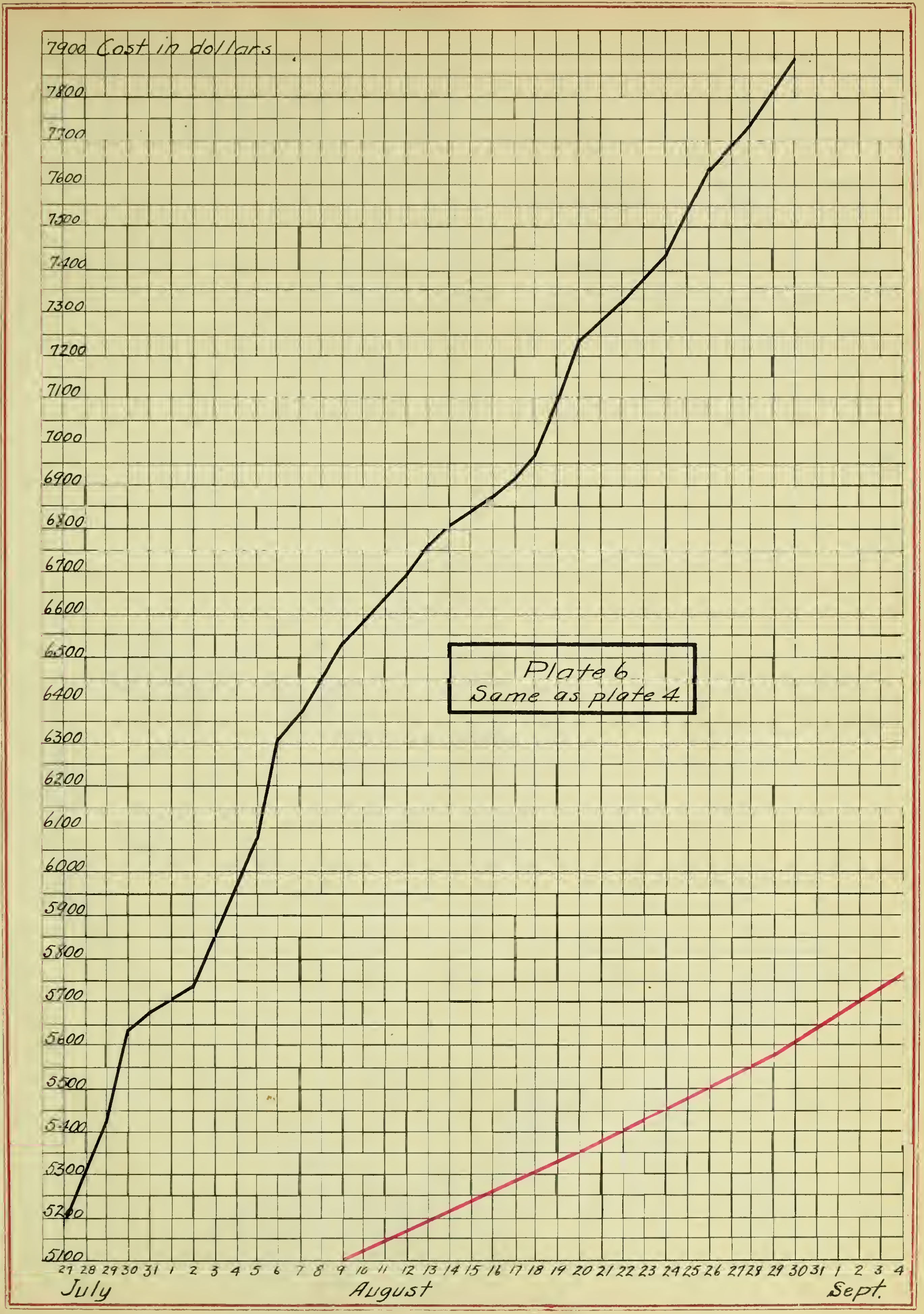


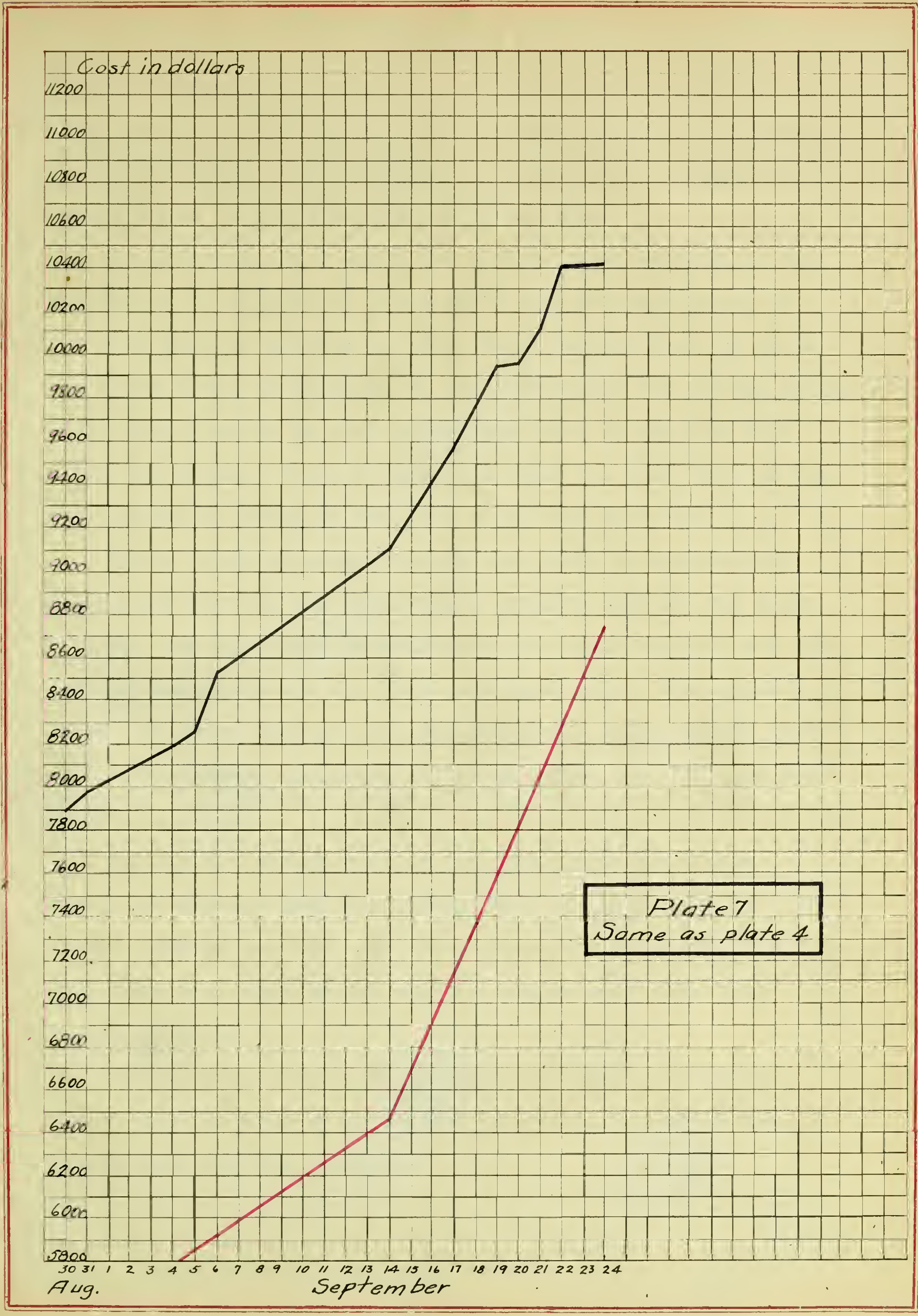
Cost in dollars
— Second Division —
Stations
July
August
Sunday
Rain
Rain(½)
Plate 2
Same as Plate 1.


Cost in Dollars
Third Division
Stations
Plate 3
Same as plate 1.
Sunday
Sunday
Sunday
Sunday
Sunday
Sunday
Rain
120
115
110
105
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
27
26
25
24
23
22
21
20
19
18
17
16
9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
August
September


Cost in Dollars
2700
2600
2500
2400
2300
2200
2100
2000
1900
1800
1700
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
Plate 4
Curves showing relation between actual cost and contract price.
Actual cost
Contract price
15 17 18 19 20 21 22 24 25 26 27 28 29 31 1 2 3 4 5 7 8 9 10 11 12 13 14 15 16 17 18 19 21 22 23 24 25 26 28 29 30
May
June


Cost in dollars
5300
5200
5100
5000
4900
4800
4700
4600
4500
4400
4300
4200
4100
4000
3900
3800
3700
3600
3500
3400
3300
3200
3100
3000
2900
2800
2700
2600
2500
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 1 2 3 4 5 6 7 8 9 10
July
August
Plate 5
Same as plate 4


Cost in dollars
7900
7800
7700
7600
7500
7400
7300
7200
7100
7000
6900
6800
6700
6600
6500
6400
6300
6200
6100
6000
5900
5800
5700
5600
5500
5400
5300
5200
5100
Plate 6
Same as plate 4
27 28 29 30 31 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 1 2 3 4
July
August
Sept.


Cost in dollars
11200
11000
10800
10600
10400
10200
10000
9800
9600
9400
9200
9000
8800
8600
8400
8200
8000
7800
7600
7400
7200
7000
6800
6600
6400
6200
6000
5800
30 31 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Aug.
September
Plate 7
Same as plate 4

although work was going on just the same. Thus, by looking at the red lines, it is easy to see how much the progress of the work was hindered in one way or another.

In plates 4, 5, 6 and 7 the actual total expense to the contractor is plotted in black while the contract price of the work done is plotted in red. When the red line is above the black line, as in plate 4, the contractor was making money. It is seen that at no time after June 29th is the red line above the black. Plate 7 shows how much the last part of the work tended to bring up the loss sustained earlier.

These total expenses include the labor on excavation, making and placing the concrete, a greater part of the back-filling, and the labor on man-holes and catch-basins, and the cost of materials and the rent upon machinery. The grand total of these expenses are $10,402.00The total amount paid to the contractor according to the contract for the work was $8,712.00.

Taking the actual cost of the main sewer mentioned above, an average cost per lineal foot is $4.02. It is evident though that part of the sewer actually cost a great deal less than this amount while a larger part cost this amount or more.

The contract price for the main sewer was $2.65 per lineal foot in cuts up to 10 feet in depth, and $3.15 per lineal foot for the remainder.

Conclusion.

The comparison between the actual cost and the contract price that has been made in this thesis may not be a fair one, yet it shows the actual results as they occurred. The reason for the comparison being unfair is the fact that the bid on the main sewer was part of a bid that was made upon the main sewer and the pipe laterals, combined. The contractor who did the work was the lowest of eight bidders upon the concrete sewer, but was the highest upon the laterals. Most likely he figured to just come out even upon the concrete work and to make his profits upon the laterals.

It is seen that not sufficient allowance was made for emergencies that occur upon work of this character. Other bidders were higher, and their average bids ranged from $4.00 to $4.50 per lineal foot which corresponds very well with the actual cost.